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ABSTRACT

This document presents an analysis of the early attending responses and orienting reactions of infants which can be observed at birth and shortly thereafter. Focus is on one specific orienting reaction, the early direction and maintenance of one's eyes and head toward certain stimuli instead of others. The physical properties of stimuli that control the response are discussed. Patterned stimuli are preferred over unpatterned ones, and the contour density of stimulus surfaces appears to be a crucial variable in controlling this preference. The second issue discussed concerns systematic changes in reactions to these stimuli as the child develops. Third, the question of how these specific physical properties might stimulate the developing nervous system is addressed. Electrophysiological studies are reviewed, indicating that contour density and other factors that interact with contour density do control the amplitudes in some components of visually evoked potentials (VEPs). Finally, the document proposes a possible description of how this stimulation might be brought under the self-control of the infant's own actions. The speculation focuses on (1) inhibitory loops in the brain, and (2) the developing receptive field between 4 and 5 months. (DP)

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BRAIN MECHANISMS INVOLVED IN EARLY VISUAL PERCEPTION

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BRAIN MECHANISMS INVOLVED IN EARLY VISUAL PERCEPTION[1]

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When an organism comes into the world he possesses a nervous system containing a great number of phylogenetically developed expectancies that predetermine behavior. These expectancies are evidenced by selective attention and orienting reactions to some stimuli as opposed to others at birth and shortly thereafter. The importance of such attention can not be too strongly stressed. Early attending responses and orienting reactions provide the infant with his first sources of information about the world. These reactions represent organized patterns of action which serve to select information on some adaptive basis around which future abstraction of environmental invariance must take place. Thus, the attending reactions of infants have been suggested to be necessary precursors of adult perceptual-cognitive abilities.

Today, I wish to examine the characteristics correlated with one specific orienting reaction, the early directing and maintenance of one's eyes and head toward certain visual stimuli over others. First, I hope to show what physical stimulus properties for the most part control such reactions; second, I hope to show what systematic changes in reactions to these stimuli occur over development. Third, I hope to show how these specific physical properties might stimulate the developing nervous system, and finally, I hope to propose a possible description of how this stimulation might be brought under the self-control of the organism's own actions.

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First, specific physical properties of stimuli affect visual orienting, Fantz, in recent times, opened up significant avenues of investigation when he found that infants are far more attracted to patterned stimuli than to non-patterned stimuli. The features of patterns that appeared relevant for such reactions, however, were not at all clear. Much subsequent research has been generated to clarify this particular issue. However, a review of data from my own and others' studies indicates that the degree of visual orientation or duration of fixation appeared at least to relate in a major way to the average contour density of stimulus surfaces. That is, looking can be ordered by some measure of black-white transitions or contours contained in stimuli that takes into consideration the quantity or amount of contour present and the area over which this contour is distributed (Karmel, 1969a).

Arrangements of contours within patterns do not appear to play a great role in the magnitudes of pattern preferences unless these arrangements greatly affect local density values within the pattern. The first slide [Figure 1] shows the original stimuli used in an operational support for an ordering of fixation preferences based on the average contour density continuum. Here stimuli are shown having either an ordered (i.e., redundant) or a disordered (i.e., random) arrangement of checks. The average contour density across the set of patterns varied, yet the average contour density within any single pattern was constant. If average contour density can be represented by a quantitative measure of black-white transitions at the retina, then magnitude of duration of looking can be shown to follow a shifting set of inverted U-shaped curves. Slide 2 [Figure 2] depicts hypothetical curves derived from my own studies (Karmel, 1969a), and those of Hershenson (1964), Brennan, Ames, and Moore (1966) and Greenberg and O'Donnell (1972) for dependent

measures of total time spent looking at patterns presented using Fantz-type infant observation techniques. The use of the square root of the sum of the lengths of all black-white transitions, (given some standard for distance and area to describe contoured stimuli) yielded inverted U-shaped functions whose maxima progressively shift to higher density values with age. The ordinal relationships in looking duration between stimuli across studies could be predicted by these functions.

Further, stimulus variables affecting the relative contrast between contours might also affect preference curves. First, luminance differences change the functions systematically. Pattern preferences become poorly defined at low luminance levels across ages. Increasing luminance to moderate levels sharply defines differences along the edge continuum (McCarvill, 1973). At the same time, preference to patterns with eccentrically varying density, such as a bull's-eye, can be shown to interact with average contour density (Maisel and Karmel, 1973). Thus, contour density of visual stimuli appears to control early visual attention in infants with shifts at moderate levels of intensity occurring toward greater contour densities with development.

Because of the similarity of orienting reactions in animals (Karmel, 1969b), because of the presence of reactions to patterns at birth or shortly thereafter (Hershenson, 1964), and because of the general maturational character of the orienting response over development (Fantz, 1965), and a host of other reasons implicating correlations of neural development with these reactions in infants, it appeared that theoretical models and empirical studies of how the nervous system responds to patterned stimuli in infants and other developing organisms could prove useful in attempts to determine the mechanisms involved in early visual reactions.

Neurophysiologically, Hubel and Wiesel (1962) have assessed the effects of patterns and contours on the visual system by evoking spiking activity changes in single neurons. However, other changes in brain electrical activity can be recorded on a more macro-physiological level by noting the evoked changes in very slow occurring potentials recorded in or near neural tissue.

In humans this operation would entail recording potential changes in the EEG from scalp leads for some period of time (usually one sec.) after the stimulus is presented. The effects of evoked spike rate changes at the single unit level have been shown to correlate to potential changes evoked in the EEG, but the details and mechanisms behind this correlation are unknown or at least speculative. Since the single unit level of analysis is impossible to record in human infants, we decided to record those scalp potentials evoked when visually-patterned stimuli are presented for viewing.

The effects of patterned stimuli on visually evoked potentials (VEPs) in adults have been documented by others. Regan (1972) and MacKay (1969) have summarized this work. Patterned stimuli systematically affect the amplitude and latencies of positive and negative voltage peaks (components) occurring in the brief interval following a stimulus. Such variables as contour density, sharpness of focus, and luminance are known to alter various aspects of components of the VEP. Thus, it seemed reasonable to measure VEPs in active, awake and attending infants, first to find out whether there were changes in infant VEPs which could reflect patterned stimuli, and second, whether these changes were related to behaviorally derived preference curves. The first evoked study used only redundant checkerboards and tachistoscopic presentation of patterns, since most adult VEP studies and infant preference studies in-

cluding my own have used these stimuli, and since pilot studies indicated a limit to the number of VEPs we could obtain in infants because of the duration of the task.

Generally, we have been able to obtain reliable evoked potentials by first attaching a lead to the occipital pole on the scalp and a reference lead to the back of one ear. We use a telemetry system to measure the EEG to eliminate cumbersome leads. The infant is taken into a shielded room, and bottle-fed by its mother to reduce movements. Finally, while being fed the infant is oriented toward a screen where a pattern is exposed briefly for less than 1 msec. Thus, the infant sees a tachistoscopic flash of light which is patterned. This flash of patterned light is repeated a number of times for reliability (32 in our studies). After the flash, the EEG is computer averaged every consecutive 4 millisecs for approximately 1 sec. Further, we averaged only on those trials when S was judged to be looking toward the stimulus. After the VEP for one pattern had been obtained, a new pattern was flashed and the averaging began again.

Two chronological age groups of 9 and 12 week-old Ss were tested. The data summarized responses of 33 Ss from whom we were able to obtain five different VEPs. There were four VEPs to patterned stimuli where density varied between patterns and one to a so-called "blank" which was equated in total area and in the amount of light present in the patterned stimuli, but contained no contour except for its outline.

The typical VEP components are shown in the next slide [Figure 3]. Using these procedures we found four reliable components, N_1, P_2, N, and P_4, across stimuli and objects. These peaks were defined as follows: N_1 - the first

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negative component prior to 100 msecs.; P_2 - the most positive peak between 100 and 200 msecs.; N - the most negative point after P_2 but prior to the first most positive point occurring after 300 msecs.; and P_4 - the first most positive point after 300 msecs. After standardization using parametric trend analyses, we found that only the amplitude of P_2 varied systematically as a function of the square root of contour. As might be predicted, this was an inverted U-shaped curve. Further, the expected interaction with chronological age occurred such that the patterns generating the greatest P_2 amplitudes contained smaller check sizes the older the S.

A second analysis was even more interesting. Ellingson (1967) has argued that the latency after stimulus onset of this particular position peak (P_2) reflects neurological development. This assumption is most reasonable given such effects as development of myelin on neural transmission rates. If Ss are regrouped on the basis of their average P_2 latency, a similar shift of the maximum amplitude was generated. Again amplitudes were larger for smaller check sizes the shorter the average P_2 latency. [Figure 4 shows this effect.] Thus, VEP components can be found to reflect contour variables and the variation of components appears to behave in a similar manner as do preference functions and shifts in preference function maxima with development. Further, these effects ride in, so to speak, with neurological development.

In this initial study, only one type of pattern configuration was used. The next study determined if variations of configuration, such as that between random and redundant patterns, would show any pattern configuration effects independent of contour density. In order to accomplish this we employed a different technique of stimulus presentation: sine-modulated light changes

through which patterns were viewed instead of the previous tachistoscopic view of the pattern.

In this technique the intensity of light exposing the pattern is varied at a highly redundant temporal rate, waxing and waning from low to high as defined in cycles of change per sec. A sine-modulated light change, i.e., temporal changes alone, will drive the EEG at a fixed frequency and amplitude which is correlated with the frequency and intensity of the changing light. Variations between patterns, i.e., spatial changes, would alter the fixed EEG effects if spatial changes result in additional effects on the EEG.

The next slide [Figure 5] shows a typical set of 12 VEPs from one S in response to 2 configurations and 5 density levels of patterned stimuli along with two "blanks" and a single temporal rate of change (4.5 cps). The VEP effect is now greatly simplified in relation to the tachistoscopically obtained responses. We can identify a positive peak (P_1) followed by a negative-positive-negative complex (N_1, P_2, and N_2, respectively). If amplitude differences between P_1 and P_2 or P_1 and N_1 are standardized across an S, a definite effect between the differing stimuli is again found across Ss and appears very clearly in the individual records. The next slide [Figure 6] plots the effect of stimuli across the 12 stimulus patterns for seven 13- and 14-week-olds. An inverted U-shaped curve to the square root of contour accounts for 80% of the significant stimulus factor variation. A product-moment correlation of .90 relates this dimension to the VEP variation.

Obviously, then, the shape of the curve was related to fixation preference functions, but do the maxima of these curves correspond for a given age? From the VEP curves we would predict a maximum for the preference function somewhere between 2°30' and 1°10' for 8 to 9 week-old infants while predicting

the maximum at 1°10' for 13 week-old infants. These values correspond exactly to those which we would predict from the hypothetical preference curves shown earlier in Figure 2.

This sine-modulation technique not only allows us to extend our arguments across more than one configuration, but it also suggests that the temporal rates of change of stimulation are powerful and specific variables that interact with VEP component amplitudes and amplitude differences in infants. Temporal rates, then, should systematically affect preferences.

Since contour density affects component amplitudes in a specific fashion over the duration of a VEP at a given age, then temporal and spatial changes should interact in predictable ways, probably dependent on what rates of change can occur in the brain at a given age. Perhaps, then, the general notions concerning effects of stimulus change suggested to be important in models of infant preferences (such as theories involving optimal levels of stimulation or optimal amounts of stimulus discrepancy) can apply, but the specific operational tests of these notions must utilize the rates of change affecting neural activity that we are reporting here. A host of predictions and interactions based on brain following frequencies and rates of change of temporal information could be made, but I would rather develop a set of empirical curves from the electrophysiological data for maximal frequency driving using temporal changes in the context of spatial patterns, and then compare these predictions with behavioral preferences not yet available for temporal frequencies.

In summary, both behavioral and electrophysiological studies indicated that the feature of patterned stimuli controlling the magnitude of attention and the amplitudes and amplitude differences in some VEP components appeared

to be the average contour density contained in stimuli. Other factors would interact with this stimulus parameter.

If magnitude of VEP components reflects degree of neural synchrony, and this synchrony is correlated with magnitude of neural stimulation, we conclude that our data provide direct support for the notion that magnitude of neural stimulation directly correlates with fixation preferences in infants.

The specific manner in which stimulation of the brain is transformed into behavioral acts of orienting still remains unclear. But two lines of inquiry and reasoning may be useful here. The first is analysis at the single neuron level and the second involves speculation on which brain structures and behavioral relationships may be involved.

Our arguments regarding how size characteriscics of receptive fields of visual system neurons interact with various stimulus check sizes (Karmel, 1969b) are similar to Armington's (Armington, Corwin, and Marsetta, 1971) which he will discuss, so I will not expound on this here. I only wish to reiterate that an inverted U-shaped curve of spike rate changes would necessarily follow variations of average contour density given a restricted receptive field size. Since receptive field sizes in general become smaller and more defined with development, it seems reasonable to conclude that their output might correlate directly with preferences and amplitude or amplitude differences in VEP components.

I will spend what time remains discussing one implication of the data which recently suggested itself given the active character developing sensory-motor reactions and recent knowledge of visual system functioning at the neuronal level.

Stimulation of the superior colliculus results directly in an eye movement of a definite magnitude and direction. The magnitudes of these movements are correlated with single unit activity in this sub-cortical region and, in addition, the magnitudes of eye movements can be shown to positively correlate with magnitudes of VEP components recorded from the scalp (Armington, 1973, personal communication). Collicular unit activity is directly inhibited by cortical stimulation principally from area 18 which has independent projection from area 17 and from the pulvinar adjacent to the LGN (McIlwain and Buser, 1968). Thus, development of an inhibitory loop from area 18 to the superior colliculus can directly control the magnitude and direction of ongoing eye excursions and thus control the resultant neural stimulation which is self-produced when patterns are displaced over the retina by these eye movements. I would like to believe that this along with development of receptive field sizes is the specific case affecting preferences.

Large saccadic eye movements over a contoured stimulus (the case for younger Ss) in addition to evoking neural activity in multiple visual regions correlated to or producing orientation and fixation, would produce a specific neural stimulation proportional to the contour in the stimulus. The effect of this stimulation would be to inhibit future eye movements or at least reduce them in size, as seems to be the case for older Ss, and reduce the probability of a repeat of the stimulation. The absence of such a loop would result in further stimulation by a large eye movement and thus continued looking, an apparent condition existing in younger Ss. An inhibitory loop along with refinement of receptive field size, as suggested earlier, may be undergoing development during the first 4-5 months of life. These factors seem to follow

all the characteristics of developing schemes of action controlling stimulation in the Piagetian sense of a primary circular reaction involving the sensory feedback of the consequence of self-produced movements (Held and Hein, 1963).

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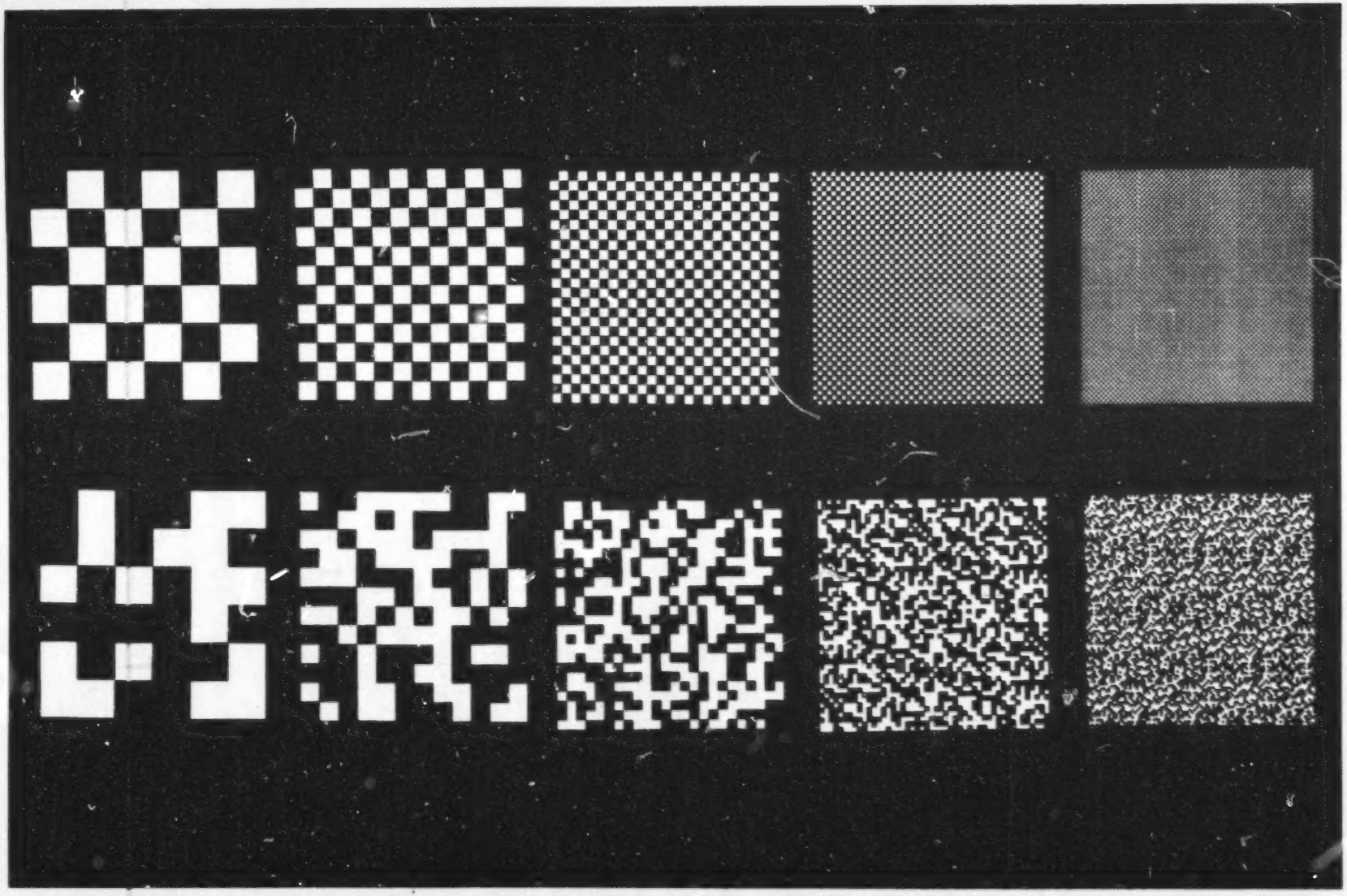

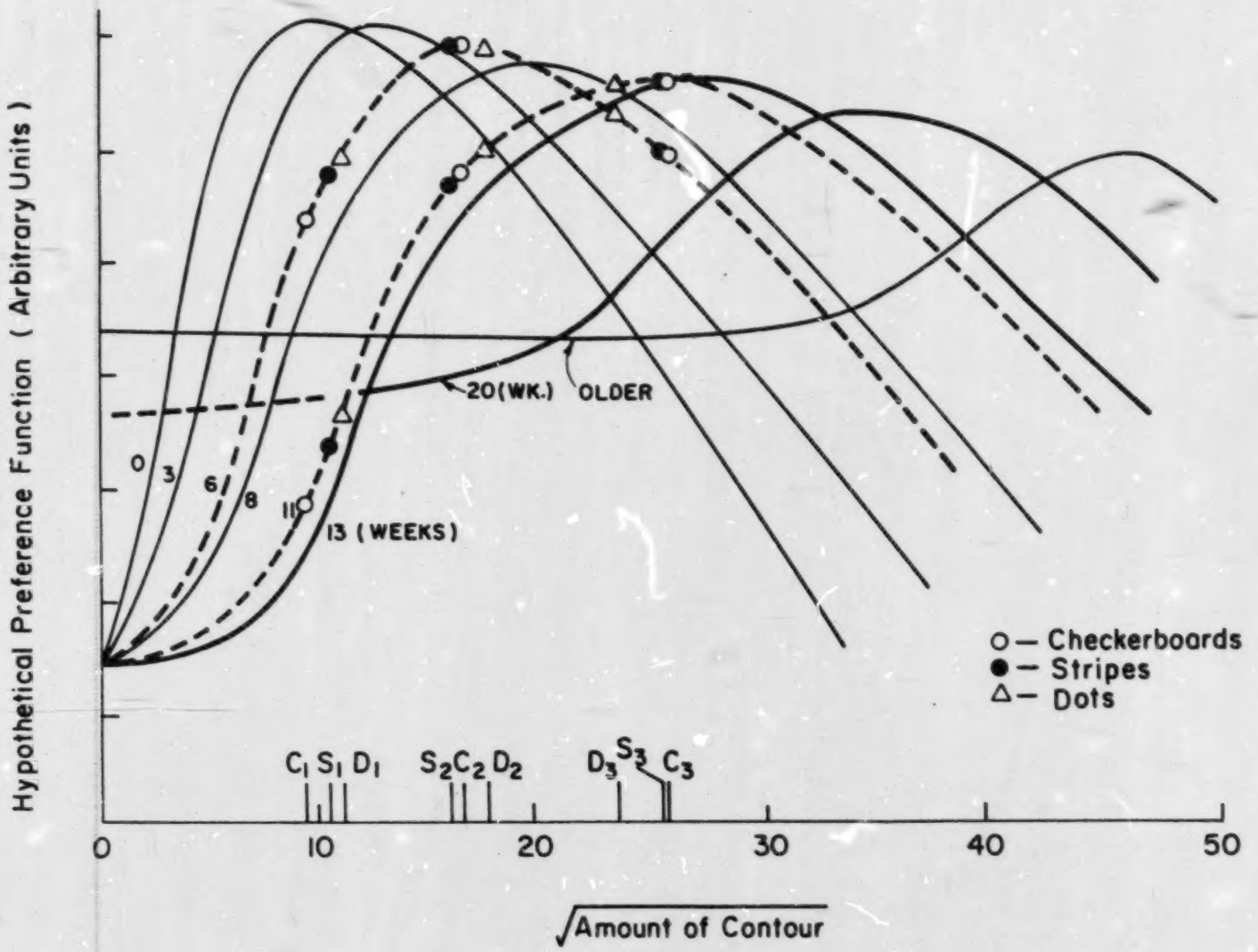
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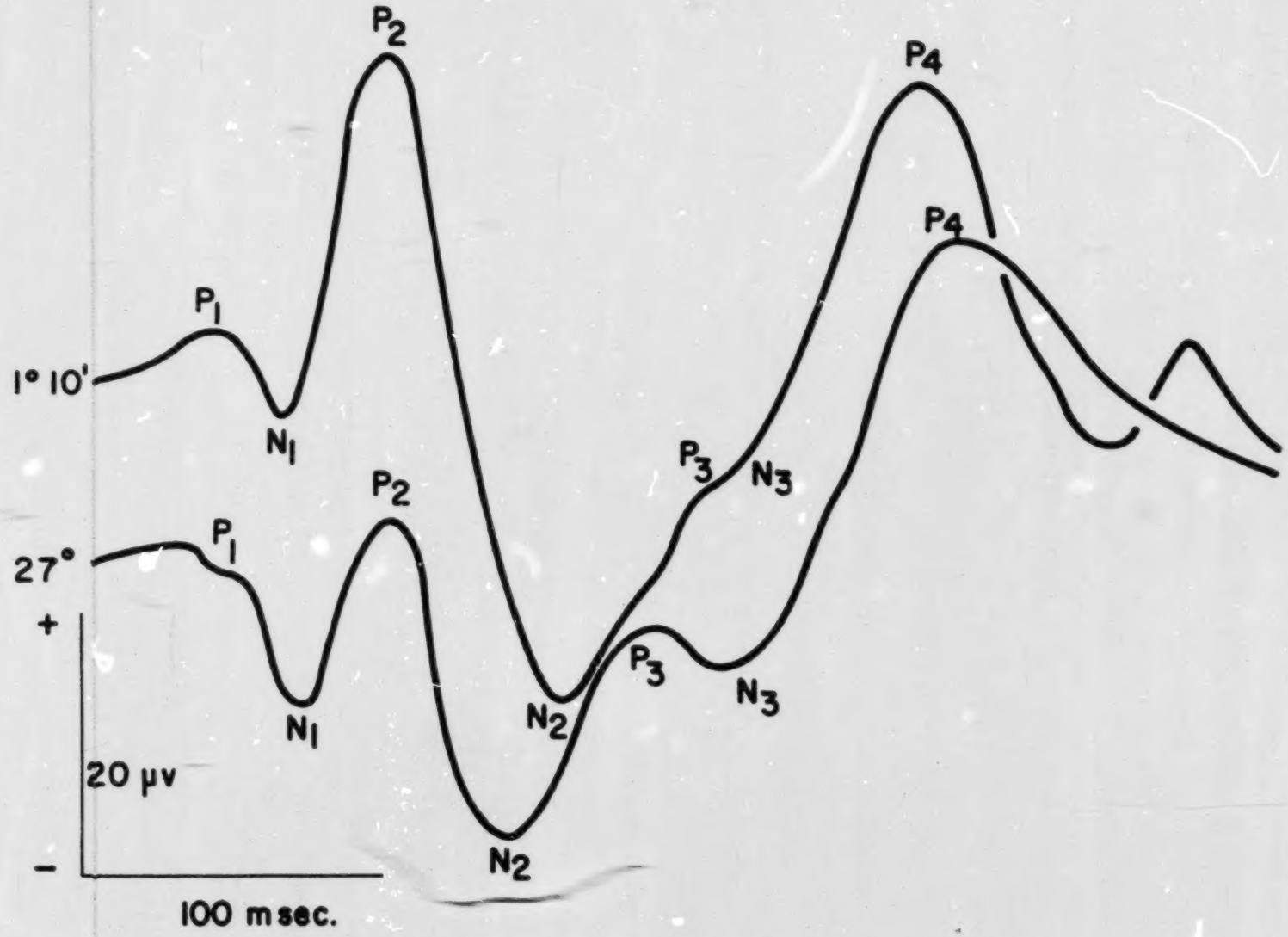
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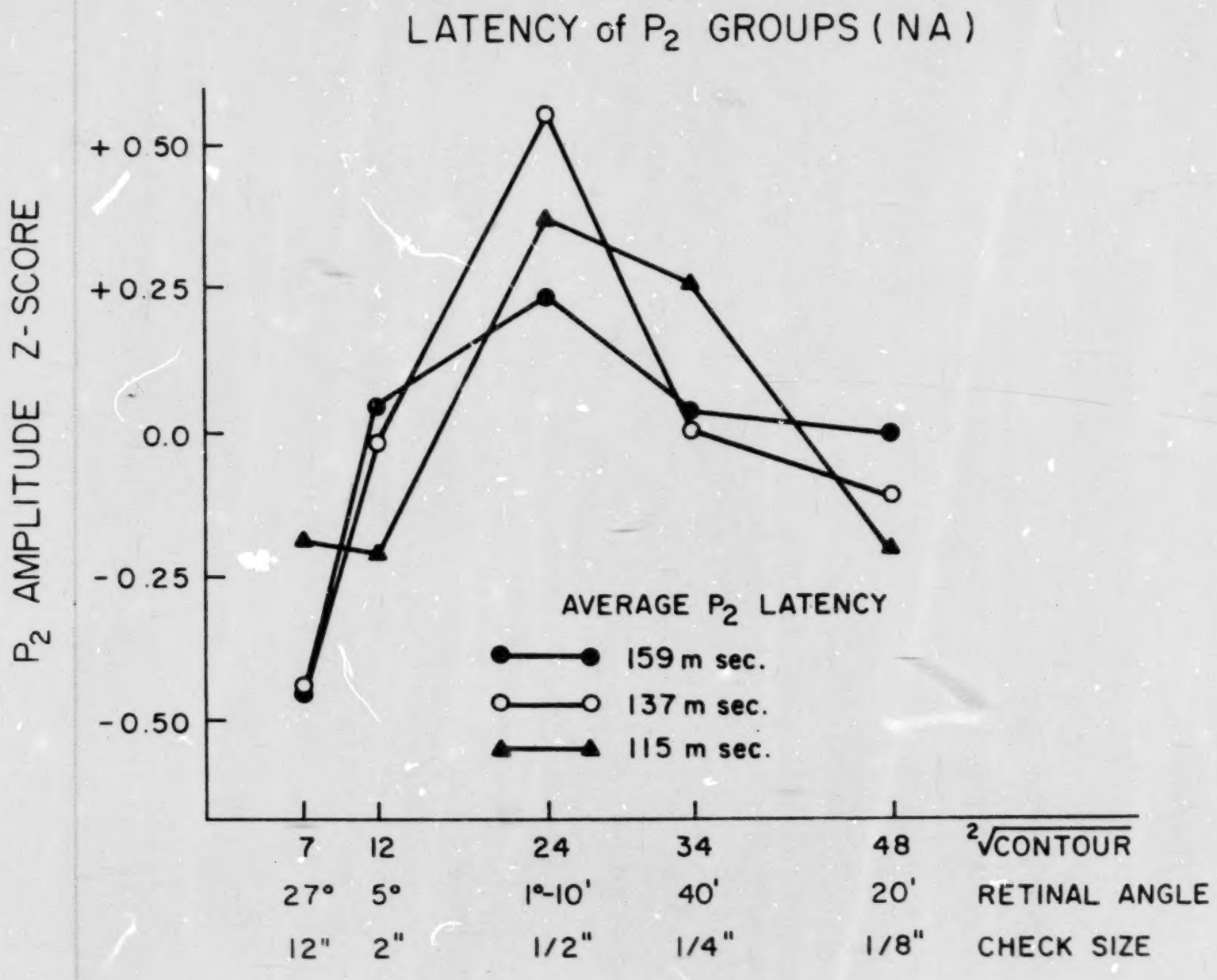
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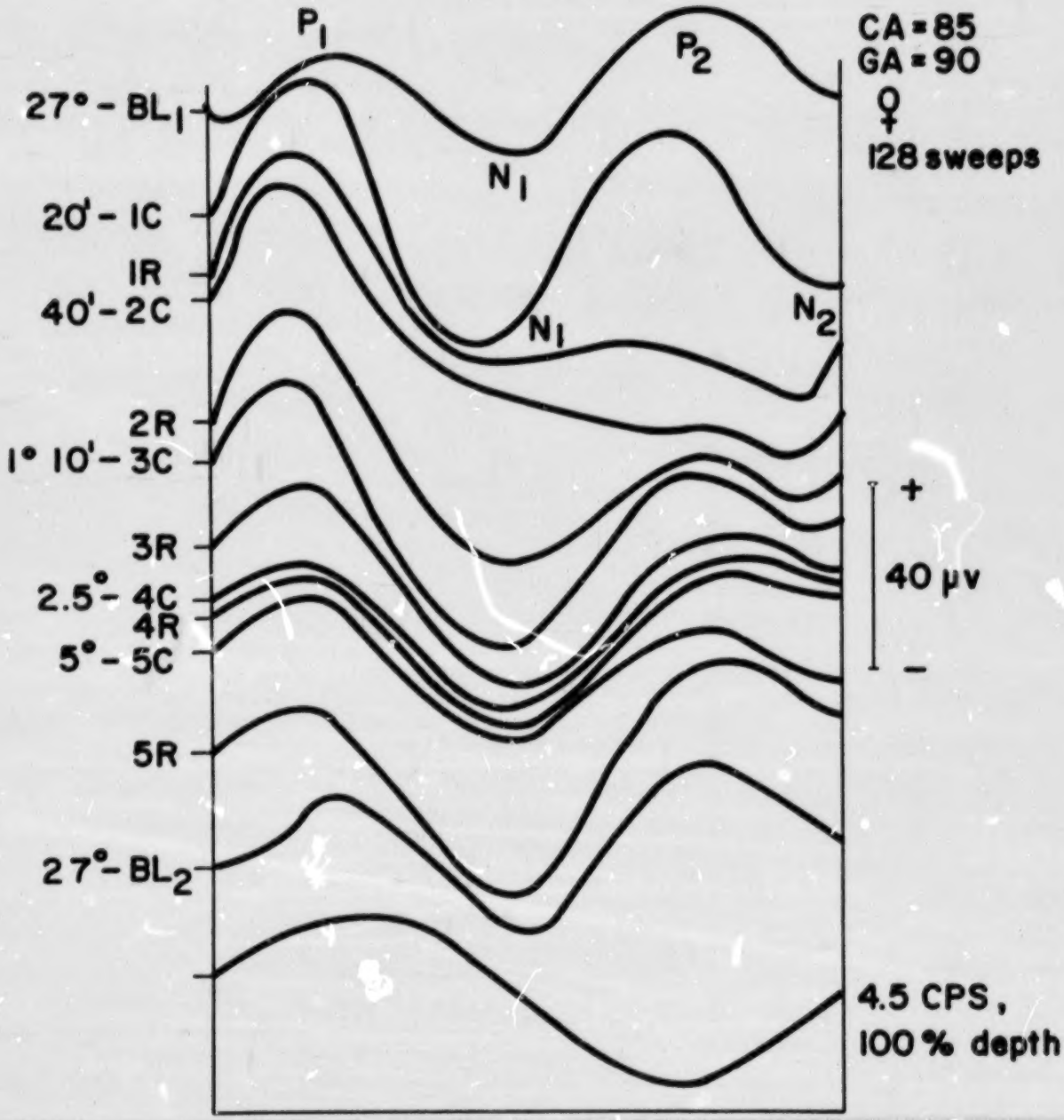

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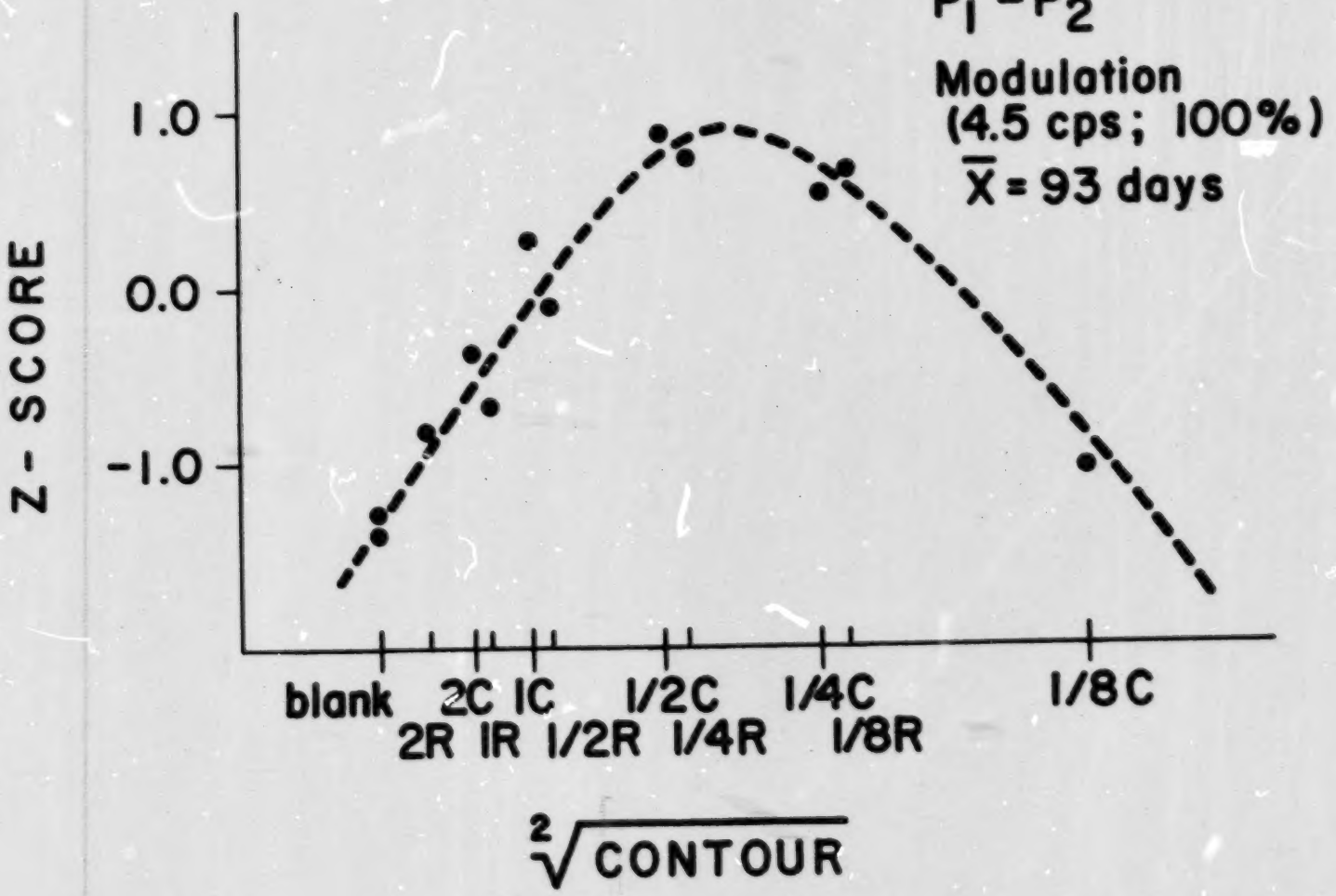
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